Lesson Introduction

Welcome to **Antimicrobial Resistance and Public Health**! Antimicrobial resistance (AMR) poses an increasingly serious threat to global health, and veterinarians must be properly equipped to assume leadership roles in addressing this challenge. This lesson is a learner-centered educational resource that was designed to enhance the quality of instruction on AMR for veterinary students, with intended impacts including **(1)** student mastery of knowledge and skills related to relevant AMR learning outcomes and **(2)** change in predicted antimicrobial usage behavior that is manifested as more judicious antimicrobial-prescribing patterns among future veterinary clinicians. These impacts will help establish veterinarians on a career trajectory that promotes antimicrobial stewardship and One Health.

This lesson incorporates the principles of learner-centered teaching, wherein instructors assume the role of facilitating student engagement in critical thinking and problem solving as a means of learning. Students are thus able to apply their knowledge to solve real-world problems related to AMR. A large body of literature points to the advantages of this approach. The lesson is an inclusive educational resource that you can integrate into an existing course using learner-centered teaching strategies. It includes a suite of online foundational instructional materials, a case-based interactive learning activity that can be incorporated into a class session, and an assessment instrument that has been tested extensively to ensure its validity. The materials in this lesson are flexible and can be easily integrated into an existing course focusing on veterinary public health concepts, to complement existing teaching methods.

✔ LEARNING OUTCOMES

The learning outcomes included in this lesson plan were designed to support the AAVMC/APLU National Action Plan to Address Antibiotic Resistance (Association of American Veterinary Medical Colleges/Association of Public & Land-Grant Universities). By the end of this lesson, students will have achieved the following learning outcomes.

1. **Describe** the public health and economic burdens posed by antimicrobial resistance among bacterial pathogens.
2. **Discuss** the impact that global population growth will have on demand for food supplies.
3. **Identify** the antimicrobial-resistant pathogens that represent the most critical threats to public health, as prioritized by the CDC.
4. **Explain** the different routes of bacterial disease transmission in common domestic species and their associated production systems.
5. **Explain** how bacteria that are resistant to antimicrobial drugs can move across borders and disseminate resistance through clonal spread.
6. **Explain** how antimicrobial drug use in animals and humans can exert selection pressure and promote antimicrobial resistance.
7. **Locate** and **interpret** antimicrobial susceptibility data generated by various surveillance programs, such as the National Antimicrobial Resistance Monitoring System (NARMS).
8. **Design** a population health program that considers disease ecology and transmission to reduce pathogen exposure and thus minimize the use of antimicrobials.
9. **Recommend** an evidence-based prevention or treatment plan that minimizes the use of antimicrobials.
10. **Identify** potential reservoirs of antimicrobial-resistant bacteria and **recommend** measures to prevent zoonotic transmission.

SUMMARY OF INSTRUCTIONAL MATERIALS

The online instructional materials cover foundational information on AMR to prepare students for the subsequent learning activity. Together, they equip students with the knowledge and skills necessary to achieve the learning outcomes outlined above.

The foundational information begins with an overview of the public health and economic burdens of AMR, as well as a discussion of specific AMR pathogen threats as identified and prioritized by the Centers for Disease Control and Prevention

(CDC). To understand how AMR bacteria are transmitted to susceptible hosts, we then take a step back and examine the concept of reservoirs of infection, followed by the various modes of disease transmission. Next, we explore the mechanisms by which AMR emerges and disseminates. We conclude with an introduction to antimicrobial stewardship and a discussion of the role of the National Antimicrobial Resistance Monitoring System (NARMS).

SUMMARY OF LEARNING ACTIVITY

Students will need to independently complete the online instructional materials prior to attending class. During the class period, students will work through a classroom activity in small groups with instructor facilitation.

The interactive learning activity places emphasis on the application of interdisciplinary foundational knowledge to promote strong clinical decision-making and judicious use of antimicrobials in animal production systems. Students are challenged to examine AMR issues from numerous facets and to reconcile multiple and sometimes competing perspectives. The learning activity adheres to the principles of learner-centered teaching, wherein instructors will assume the role of facilitating student engagement in critical thinking and problem solving as a means of learning.

This case-based activity centers around an outbreak of *Salmonella* Dublin on a dairy farm. Working in small groups, students navigate the case and must make decisions regarding whether antimicrobial therapy should be initiated, which antimicrobial agent should be selected, and which animals should be treated. Students must then devise a list of preventive measures they will recommend to minimize the risk of zoonotic *Salmonella* transmission on the farm. Lastly, students will develop a series of herd management strategies that can be implemented to control this disease outbreak and minimize antimicrobial use on the dairy farm, now and in the future.

The case-based activity can be run in-person or remotely using a web-based platform that supports small group breakout rooms. Approximately 2 hours should be set aside for students to navigate this case. This includes time for a wrap-up discussion following each of the four decision points, during which the instructor can summarize key issues and address any learning gaps. Students should work in small groups (about 5 or 6 students per group) as they discuss relevant issues and try to reach a consensus at each of the decision points. Whiteboards work particularly well for allowing students to record and share their ideas during the small group work. Online polling software is one way for student groups to submit their answers, providing an opportunity for formative assessment. Alternatively, instructors may prefer to call on groups to provide their answers and rationale. Either way, each student group should have a designated spokesperson. Some wrap-up discussion topics corresponding to each of the decision points are included below.

DECISION POINT 1

Should you treat any animals on this farm with an antimicrobial drug?

If no, why isn't antimicrobial therapy indicated?

If yes, why is antimicrobial therapy indicated?

Treatment with an antimicrobial agent is indicated in this presumptive *Salmonella* Dublin outbreak. Bacteremia is extremely common among calves infected with *Salmonella* Dublin, and mortality can be high. In fact, bacteremia is a common sequela of *Salmonella* infections caused by other serotypes in calves as well, particularly neonatal calves. Other types of salmonellosis are associated primarily with enteric disease, but bacteremia may result in secondary infections such as septic arthritis and meningitis. Thus, antimicrobial therapy is justified to try to improve clinical recovery among calves with severe, acute salmonellosis, especially those with evidence of systemic disease. Nevertheless, it is important to remember that an antimicrobial agent is a component of the overall treatment regimen, along with fluid and electrolyte replacement, proper nutrition, and appropriate nursing care. Fluids can be administered PO or IV, depending on the degree of illness.

The main potential drawback of antimicrobial therapy is promotion of drug resistance, which may have implications for the farm and beyond. Another factor to bear in mind is that antimicrobial therapy may not limit the duration of fecal *Salmonella* shedding. Economic cost is always a consideration as well.

DECISION POINT 2

Which antimicrobial drug(s) will you use and why?

Which animals will you treat and why?

Selection of antimicrobial agent should ideally be based on identification of the organism and results of susceptibility testing, although the reality of practice frequently demands that decisions on antimicrobial use and selection be made prior to receipt of such data. *Salmonella* isolates from dairy cattle are frequently resistant to ampicillin, streptomycin, and tetracycline. In contrast, isolates are generally susceptible to aminoglycosides, fluoroquinolones, and trimethoprim/sulfamethoxazole. However, choice of drug will be largely determined by legal restrictions on antimicrobial use. For example, extralabel use of fluoroquinolones in food animals has been prohibited in the United States since 1997, and enrofloxacin is only approved for use in dairy cattle less than 20 months of age (for treatment of respiratory disease caused by specific pathogens, using either a single-dose regimen or daily administration for up to five days). Gentamicin and amikacin are not approved for use in cattle, and the American Veterinary Medical Association (AVMA) and other groups have advised that aminoglycosides not be used in extralabel fashion in cattle. Certain uses of ceftiofur and other cephalosporins in cattle are also prohibited.

Florfenicol, tulathromycin, and ceftiofur are all reasonable choices for treating pneumonia in calves. Extralabel use of enrofloxacin is prohibited, so knowing the diagnosis of *Salmonella* Dublin precludes its legal use. Use of ceftiofur to treat or control an extralabel disease indication is acceptable, but this use must stay on the labeled dose, route, and duration for dairy cattle.

Regarding which animals to treat, antimicrobial therapy is indicated for calves with severe, acute salmonellosis, especially those with evidence of systemic disease. Antimicrobial therapy is not justified for calves with mild or no clinical signs, as well as calves with chronic disease.

DECISION POINT 3

How will you minimize the risk of zoonotic transmission on this farm?

Create a list of 5–10 strategies.

Dairy farm workers and their family members often become infected with *Salmonella* during disease outbreaks in the herd. Several preventive measures should be recommended to minimize the risk of zoonotic *Salmonella* transmission on the farm. These include the following:

1. Don’t drink unpasteurized milk or allow raw milk to leave the dairy.
2. Practice frequent hand washing with soap and water, especially after work and before eating. This is a simple yet highly protective step.
3. Disinfect boots and equipment thoroughly, first cleaning to remove superficial organic debris and then using a disinfectant approved to kill *Salmonella*.
4. Keep coveralls and boots out of the house.
5. Utilize disinfectant footbaths at the entrances and exits of barns and the milking parlor. These should be carefully maintained to maximize efficacy.
6. High-risk members of the population, such as children under the age of 5 years, elderly adults, and immunocompromised individuals, should avoid contact with infected cattle and pay special attention to hand hygiene.
7. Minimize personnel contact with sick calves. Separate coveralls and boots should be worn when handling infected calves.
8. Remember that *Salmonella* Dublin has a predilection for causing invasive disease with relatively high case fatality among human patients, as compared to other *Salmonella* serotypes.

DECISION POINT 4

What does the farm do well and what could be improved?

What recommendations will you make about farm management?

Several herd management strategies can be implemented to control this disease outbreak and minimize antimicrobial use on the dairy farm, now and going forward.

1. Isolate infected animals to the extent possible, bearing in mind that some animals are subclinically infected. The magnitude of fecal *Salmonella* shedding is high. The concentration of *Salmonella* within the manure of an infected cow ranges from 10^2 to 10^7 organisms per gram of feces.
2. Maintain a dedicated maternity pen that is entirely separate from the sick pen.
3. Improve maternity pen hygiene to minimize the risk of *Salmonella* exposure among calves. Maternity stalls should be cleaned and disinfected between each calving.

4. Promptly remove calves from the maternity pen and ensure adequate and timely administration of colostrum. Within 3 hours of birth, 3–4 quarts of pasteurized colostrum should be fed.
5. Minimize personnel contact with calves, especially those that are sick; having specific individuals dedicated to calf care is ideal. If certain personnel are responsible for all the calves, these individuals should handle the healthy ones first. Separate coveralls and boots should be worn when handling infected calves, and boots should be cleaned and disinfected following use. Similarly, all feeding equipment used with sick calves should be cleaned and disinfected afterward.
6. After cleaning superficial organic debris from surfaces, use a disinfectant approved to kill *Salmonella*.
7. Consider feed contamination as a potential source of *Salmonella* exposure, as well as contaminated feed transport equipment, feed bunks, and feeding utensils. These should be cultured and disinfected as needed. It is also important to ensure that feed transport equipment is not used for other purposes, such as bedding removal, which could result in contamination with manure.
8. Consider water contamination as another potential source of *Salmonella* exposure, as well as contaminated water troughs and buckets. These should be cultured and disinfected as needed.
9. Consider flush water systems for manure removal as a possible source of within-herd *Salmonella* transmission. Flow patterns of flush water should be evaluated.
10. Recognize that group housing of pre-weaned calves increases the risk of *Salmonella* transmission. Individual calf hutches or pens are more labor-intensive but reduce the risk of pathogen transmission.
11. Recognize that new herd additions, included heifers returning from off-site raising facilities, are a potential source of *Salmonella* introduction into the herd. Suitable biosecurity measures should be implemented accordingly, including animal testing and isolation as appropriate. Maintaining a closed herd is another option.
12. Recognize that human and vehicle traffic is also a potential source of *Salmonella* introduction into the herd, further underscoring the need for appropriate biosecurity measures. These include use of clean or disposable boots and footbaths.
13. Recognize that wildlife such as rodents and birds is another potential source of *Salmonella* introduction into the herd. Thus, it is important to minimize wildlife access to feeds.
14. Maintain proper nutrition, ventilation, and protection from weather extremes.
15. Consider using vaccination as a control measure to be used in conjunction with other farm management practices. Modified-live *Salmonella* vaccines induce humoral and cell-mediated immune responses, both of which are needed for effective protection against this pathogen.
16. Implement a *Salmonella* surveillance program.

ABOUT US

The focus and scope of these resources were initially formulated by Dr. Kevin Cummings and Dr. Jodi Korich, as a means of addressing the AMR challenge through veterinary education. We assembled a multidisciplinary team of collaborators, with collective expertise in epidemiology, public health, microbiology, pharmacology, food animal medicine, companion animal medicine, instructional design, educational technologies, and program evaluation. Dr. Cummings serves as an Associate Professor at Cornell University College of Veterinary Medicine. He has been teaching epidemiology and public health to students for the last 20 years. He strives to find creative, dynamic ways to engage students as active participants in the learning process. His research focuses on antimicrobial resistance, foodborne pathogens, and emerging infectious diseases among hosts ranging from dairy cattle to wildlife. Dr. Korich serves as the Associate Dean for Education at Cornell University College of Veterinary Medicine. Her professional interests include technology-enhanced teaching and competency-based veterinary curricular design.

ACKNOWLEDGMENT

These educational resources are supported by a Higher Education Challenge Grant (award number 2018-70003-27662) from the USDA National Institute of Food and Agriculture.